Demonstration of a multimode, longwave infrared, imaging system on an unmanned aerial vehicle

Terry L Jones,[a] John G. Romanski,[b] John J. Buckley,[b] Anthony J. Girata[c]

[a] Joint Precision Strike Demonstration Project Office, 10401 Totten Rd., Ft. Belvoir, VA 22060

[b] Northrop Grumman Corp., PO Box 746, MS G8, Baltimore, MD 21203

[c] DCS Corporation, 1330 Braddock Place, Alexandria, VA 22314

ABSTRACT

The Reconnaissance, Infrared Surveillance, Target Acquisition, 2nd Generation Technology (RISTA II) sensor was integrated into the Altus Unmanned Aerial Vehicle (UAV) and flown over Camp Roberts and Ft. Hunter Liggett, CA in July 1998. The RISTA II demonstration system consisted of a long-wave infrared imager, a digital data link, and a ground processing facility (GPF) containing an aided target recognizer (AiTR), data storage devices, and operator workstations. Imagery was compressed on the UAV and sent to the GPF over a 10.71 Mbit per second digital data link. Selected image frames from the GPF were sent near real-time over a T1 link (1.5 Mbit per sec) to observers in Rosslyn, VA. The sensor operated in a variety of scanning and framing modes. Both manual and automatic sensor pointing were demonstrated. Seven flights were performed at altitudes up to 7500m and ranges up to 60 km from the GPF. Applicability to numerous military and civilian scenarios was demonstrated.

Keywords: Infrared, Unmanned vehicle, UAV, RISTA, RISTA II, Aided target recognition, ATR, Reconnaissance, Surveillance, Thermal imaging

1. INTRODUCTION

1.1 Background

The RISTA II system was designed to provide rapid, wide area surveillance and aided target detection of high value, mobile targets from an unmanned aerial vehicle. Its sensor is a modification of a scanning, mine detection sensor.[1] The primary modification was the added capability for conventional, real-time framing mode image generation. The sensor uses second generation infrared (SADA II) thermal imaging technology. Its design and performance characteristics have been previously described.[1,2,3] The sensor is very adaptable. It has been integrated into and flown on a helicopter, twin engine propeller planes and a jet fighter. A subset of the RISTA II system capabilities was demonstrated using a manned aircraft at Ft. A.P. Hill in July of 1996.[3] It was demonstrated in the role of a mid-altitude reconnaissance sensor through flight tests in an F16 in the summer and fall of 1997.[4] The success of these tests has led to the procurement of RISTA II sensors by the Royal Danish Air Force for this mission.

1.2 Objectives

This paper describes the significant new systems objectives and accomplishments beyond previous RISTA II demonstrations:

1. Integrate RISTA II on a UAV in a short period of time without access to a Systems Integration Lab (SIL).
2. Interface with a platform Inertial Navigation System (INS) and buss structure different from the one initially intended for the sensor.
3. Provide for ground control of the sensor modes of operation and Line of Sight (LOS) in real time.

[1] Correspondence: Email: tjones@nvl.army.mil; WWW: http://peoiew.monmouth.army.mil/jpsd/home.htm; telephone: 703-704-1700.

4. Implement at low cost cross continent tasking and data retrieval in near real time.
5. Demonstrate numerous applications with various modes of operation.

1.3 Demonstration architecture

The effort described by this paper was a complete end-to-end system demonstration as originally envisioned at the outset of the RISTA II program. The sensor was installed and flown on an ALTUS unmanned aircraft. The ALTUS was piloted by an operator in a Ground Control Station (GCS) similar to one currently employed by the PREDATOR UAV. A GCS was located at McMillan Airfield about two kilometers from the ground processing facility (GPF) at the Camp Roberts Satellite Communication Station. Voice radio communication was maintained between the local demonstration director at the GPF and the GCS. However, all communication with the sensor occurred after takeoff because there was not direct line-of-sight between the two sites. This communication occurred through a bi-directional, dedicated Common Data Link (CDL) variant. The sensor was controlled remotely from the GPF. The GPF processed all imagery from the sensor, generated target reports and disseminated them. This included transmission of "chip" imagery, in near real time from the West Coast to Rosslyn, Virginia.

2. SYSTEM ARCHITECTURE

2.1 Major components

The system consisted of 4 major components as illustrated in figure 1: the UAV, the sensor, the data link and the ground processing facility (GPF).

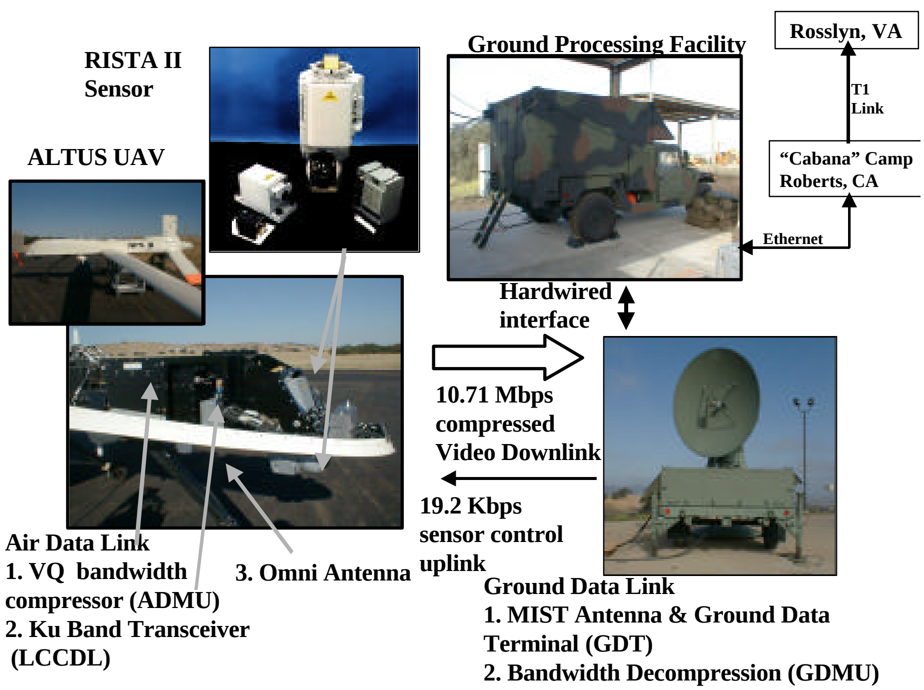


Figure 1. The RISTA II systems components at Camp Roberts, CA. The Altus Ground Control Station is not shown.

2.2 Airborne elements:

The ALTUS UAV was ideally suited to the task. Its payload capacity of 350 lbs. was in excess of that required for the sensor and airborne data link components. Its operating envelope and flight characteristics are almost identical to those of the PREDATOR UAV, the exception being that its ceiling is higher (>40,000ft). Typical cruising speed was about 90 knots. From the program outset, it was decided to provide the sensor with a dedicated data link, separate from that required to fly the aircraft. This divorced the sensor controls from the aircraft and eliminated the need for costly, time-consuming recertification of the aircraft control systems. The RISTA II sensor consisted of three line replaceable units (LRU's): sensor head, sensor electronics unit, and power supply. These units weighed a total of 140 lbs and drew 650 watts at 28VDC from the ALTUS. (The 4th LRU, the RF altimeter shown in Fig 1 was not used for this demonstration; data was taken from the ALTUS altimeter.) The sensor head was mounted in the forward part of the payload bay tilted to give a field of regard 75° forward and 10° aft of nadir. The sensor electronics unit and power supply was mounted in an open bay to the rear of the sensor head. The aircraft's inertial navigation unit was also mounted here, facilitating relay of navigation data to the sensor. The Ku band transceiver, part of the sensor's airborne Limited Capability Common Data Link (LCCDL), was also installed in this bay. To the rear of this area, a commercial, off the shelf (COTS) ruggedized 6U VME rack type chassis was mounted. This contained the vector quantization (VQ) bandwidth compression hardware and an independent single board computer used to merge uplinked data and aircraft INS information into a format compatible with the sensor's 1553B data buss. The VQ bandwidth compression hardware provided 10.71 Mbps of downlink capacity at approximately an 8:1 compression of the sensor video. Platform and other navigation data, embedded in the sensor's video data stream, were transmitted without compression. VQ compression schemes have an inherent advantage for this application: the impact of a mild bit error rate is restricted to small segments of the sensor imagery.

2.3 Ground elements

The RISTA II ground segment consisted of two primary components: The ground data link elements and the ground processing facility. The data link consisted of the MIST antenna, RF processing and antenna tracker sections (Ground Data Terminal-GDT), as well as the VQ decompression unit and uplink interface (Ground Data Management Unit-GDMU). The antenna was controlled from a hardened shelter (not shown in Figure 1) which housed the tracker and ground data terminal. The ground processing facility consisted of a HMMWV containing a RAID, Silicon Graphics Challenge L server and several workstations for operating the sensor, monitoring mission status and observing the imagery. The aided target recognition algorithm processor, or AiTRAP, was also installed in the vehicle.[3] An additional portable tent like shelter or "cabana" (not shown) was used to house the GDMU, instrumentation recorders, an auxiliary SGI server and additional workstations. The cabana's server and workstations were interfaced via ETHERNET, to the ones within the HMMWV. These augmented the storage capacity for processed imagery and provided demonstration display stations. These stations duplicated the sensor imagery and control displays within the HMMWV in a shelter more conducive for demonstration to a large audience. The ETHERNET was extended, using a fiber optic relay, to a T1 modem located in the SATCOM station building at Camp Roberts, CA. A dedicated leased T1 line extended the ETHERNET to several workstations in Rosslyn, VA. The East Coast workstations operated seamlessly across the commercial link, as if they were physically on the West Coast.

3. SYSTEMS INTEGRATION

3.1 Airborne systems integration

The integration of the airborne systems elements posed two significant challenges: 1. Integration of information from components using different buss structures and protocols. 2. Limited access to the host aircraft and a short amount of time for integration. The nature of the ALTUS UAV eliminated some of the more classical airborne system integration problems: The platform had more than adequate payload capacity in terms of volume, weight, and prime power availability. The functional interconnection of the principal parts is illustrated in figure 2.

3.1.1 Interfaces

The principal interface with the aircraft is with the inertial navigation unit (INU). This aircraft was equipped with a Litton LN-100G INS/GPS combination. Navigation data was provided to the sensor and other air vehicle systems via an RS-422 interface. Uplink commands were provided by the data link also via an RS-422 interface. The sensor on the other hand, was designed and equipped to be controlled and communicated with via a MIL-STD 1553B interface. A custom differential TTL interface connected the sensor's output data stream with the VQ compressor in the ADMU. A custom interface also connected the limited capability common data link (LCCDL) with the ADMU. A Radstone 68040 based Single Board computer was added to the ADMU. This was functionally isolated from the bandwidth compression and link interface functions, drawing only power from the 6U backplane. This computer was equipped with two RS-422 interfaces (input only) and a MIL-STD 1553B interface (bi-directional). The computer read packets from the LN100G, which contained aircraft location, velocity, attitude and attitude rate information. The other RS-422 port read mode and pointing command information from the uplink. Data was interpreted and reformatted to the existing RISTA II sensor 1553B message structure, then retransmitted to the sensor. The 68040 software also provided the opportunity to add several "fail safe" functions. These included automatic STOW of the sensor when the UAV altitude fell below a threshold or during a data link loss and monitoring of the quality of INS information.

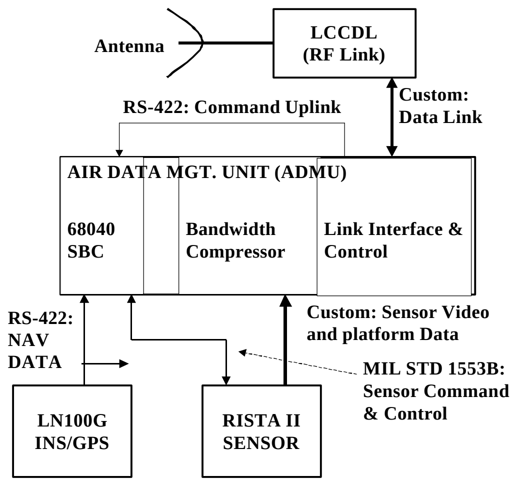


Figure 2. The sensor and data link integration had to be accomplished using a number of different buss interfaces and protocols.

3.1.2 INS simulator

A major concern during the course of the program was access to the aircraft. Since the ALTUS was a "one of a kind" air vehicle, no system integration laboratory (SIL) existed. Since mechanical installation was never a problem, the chief concern was to develop the ability to emulate interfaces with the INU. Fortunately, a software package which emulated the outputs of the LITTONLN100-G was located. This could be loaded onto any laptop or other PC equipped with an RS-422 interface. The operator entered heading, altitude and speed via a graphical user interface illustrated in Figure 3. The operator also entered a starting latitude and longitude for the flight segment. The simulator then generated a continuous stream of data packets in a format and sequence identical to the actual unit. After the fidelity of the simulator was checked against the actual aircraft INS outputs, the simulator was used to check the interfaces to the sensor. The utility of the simulator was further extended to actually "fly" missions during system integration without the aircraft present. Thus, complete air to ground systems checks, minus the RF link, were performed quickly and efficiently.

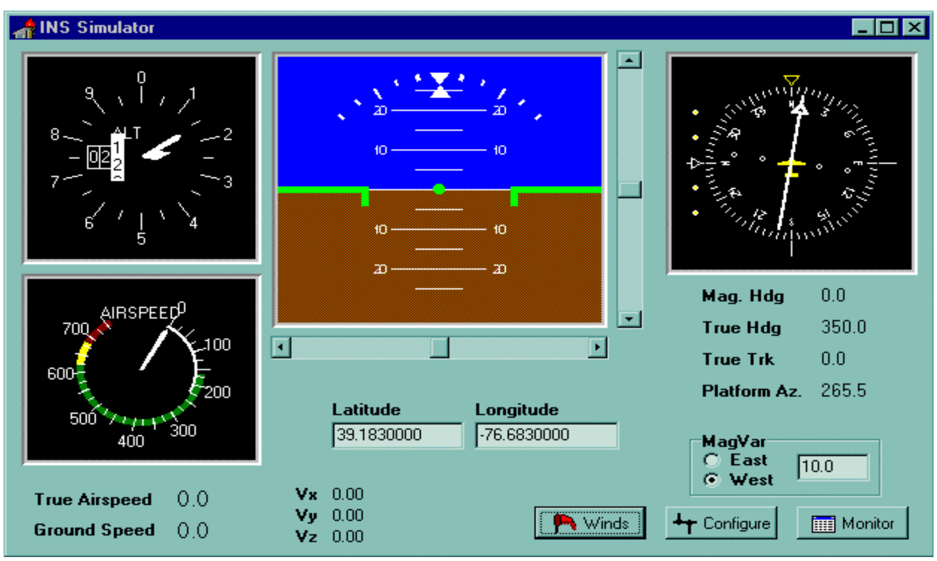


Figure 3. The INS simulator shown proved to be an indispensable tool for shortening the overall system integration time and substituting for limited access to the aircraft.

3.2 Ground segment integration

This section describes the ground segment integration: the ground segment architecture, mission monitor, and sensor control.

3.2.1 Ground segment architecture

The ground segment architecture is illustrated in figure 4. Imagery data from the downlink was acquired in one of two sensor imaging modes: scanning or framing. The ground segment handled them differently.

1. Scanning. The sensor generates wide swaths of data in a ground stabilized push broom scan pattern. Typically, a swath contains 480 x 16,000-23,000 pixels. The number of pixels in the horizontal direction depends upon aircraft velocity over altitude and adapts to current flight parameters. The scan data was stored on the RAID. Software was provided for the off-line reconstruction and viewing of this WFOV imagery. The line scan imagery was processed simultaneously by the AiTRAP. Small full resolution image segments or "chips" containing the candidate targets were displayed to an operator using a chip display window and could be assigned to any of the workstations. The operator either retained or disposed of the target using the graphical user interface (GUI) illustrated in figure 5. If retained, a target report was automatically generated and archived. The target report and corresponding image chip could be viewed from any workstation on the net, including those in Rosslyn VA.

2. Framing. The sensor operated as a conventional FLIR in this mode. The frame rate was constrained to be 15 Hz, due to link bandwidth limitations. The imagery was displayed in real time, without transport delay, to the sensor controller using an RS-170 video monitor. In addition, single frame video was sent to the target chip display at a 10Hz. Rate. The targeting workstation operator had the ability to manually generate target reports and disseminate them in the same manner as if the imagery were processed by the AiTRAP. Framing data could not be sent over the T1 line in real time for viewing in Rosslyn, only chips selected by the operator at Camp Roberts.

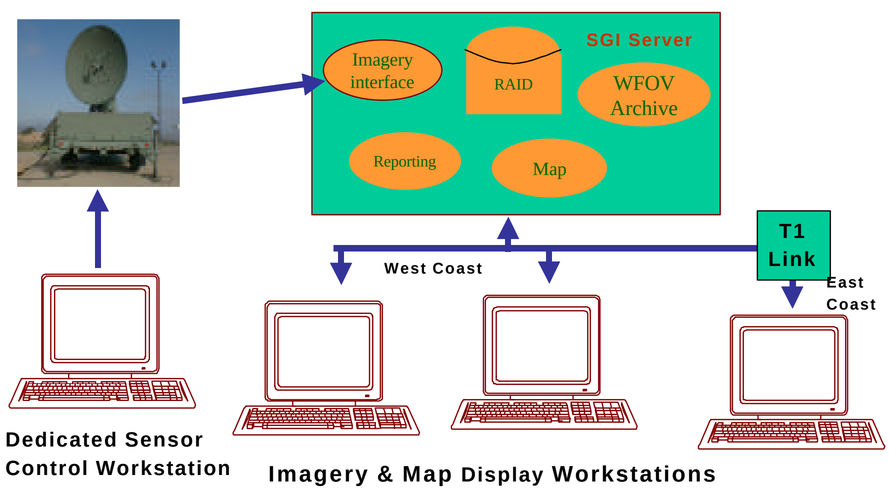


Figure 4. The Ground Segment Architecture was built around an SGI server with several slave workstations.

Figure 5. The target chip display allowed an operator to quickly verify aided target detection in the scanning mode, as well as, to manually generate target reports when the sensor was operating in framing mode.

3.2.2 Mission monitor

A mission monitor display, illustrated in figure 6, was provided to monitor mission progress. This consisted of a map showing the current location of the aircraft as well as a box or rectangle illustrating the location of the sensor coverage on the ground. In the case of framing mode, the coverage appeared as a red dot, due to the map scale. Information concerning the location of the aircraft and sensor coverage was embedded in the downlinked video to avoid latencies. This information was extracted and communicated to the workstations running the mission monitor map software via UNIX sockets. Three simultaneous displays were supported: 1. Inside the HMMWV for the sensor operator. 2. In the "cabana" area for the Camp Roberts demo attendees. 3. In Rosslyn for east coast attendees.

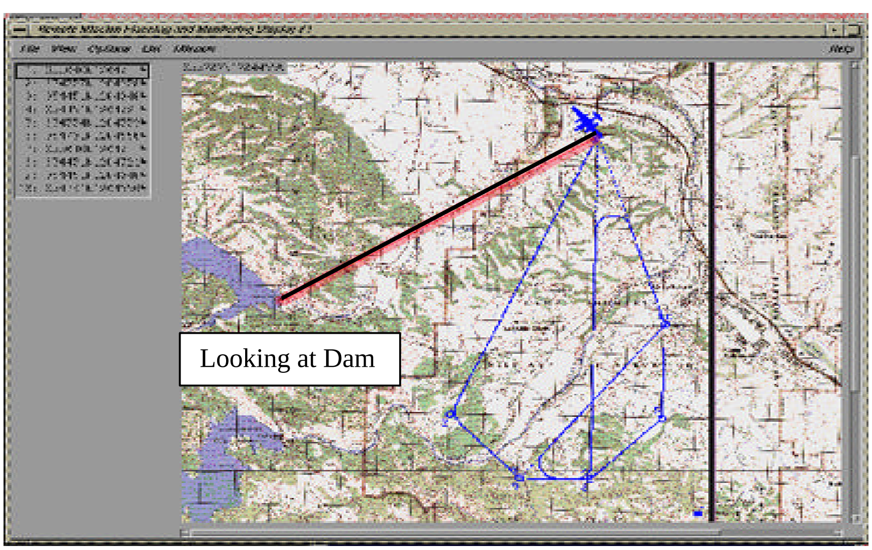


Figure 6. The mission monitor display enabled the audience to interact with the sensor. The sensor was pointed at coordinates requested by the east coast participants and target reports were generated in near real time.

3.2.3 Sensor control

A key element of the demonstration was the ability to easily control and point the sensor remotely from the ground. Past efforts to remotely control sensors in UAV's have often been plagued by transport latencies moving data from computer to computer within a ground processing system. Two design features were utilized to avoid these problems. The RISTA II sensor is equipped with its own inertial measurement unit (IMU). When properly integrated with the aircraft navigation system, the sensor can be pointed to and maintain its line of site at a geographical location with great stability. Another pointing mode enabled the LOS to be pointed at any azimuth/elevation angle relative to the stabilized North-East-Down (NED) plane of the aircraft, automatically compensating for aircraft roll, pitch and yaw. The geographical pointing information for the sensor line-of-site was concurrently embedded in the video data stream, allowing for an accurate, real-time depiction of sensor coverage on the map display. The second feature was to dedicate a high performance workstation to the sensor control task. This workstation was equipped with a graphical user interface (GUI), illustrated in figure 7. A joystick was interfaced to this workstation via a serial port. A second serial port was used to interface the workstation directly to the uplink. The link acted as a low latency relay. The operator could command the sensor mode via the control GUI into any pointing mode. A list of geographical cues to known target location could be loaded prior to a mission. The operator could command the line-of-sight to the cues. In any of these pointing modes, the operator had the capability of modifying the line-of-sight with the joystick and initiating stabilized track upon a target. The geographical location of the modified line-of-sight could be extracted from the video stream, with very low latency, and added to the target list. Thus the geographical location of targets of opportunity could be determined, retained, then used to cue the sensor during later passes or missions. The sensor could be commanded into a number of different offset scan modes as well. This permitted wide area surveillance of target areas without actually flying over them.

• A Workstation was dedicated to sensor Control ensuring a low latency control path

• Graphical User Interface (GUI) was rapidly prototyped using a Higher Order Language, TCL

Figure 7. Dedicating a high performance workstation to the sensor control task eliminated data latency issues and permitted the use of a higher order language for rapid development of the control software

4. DEMONSTRATION RESULTS

4.1 Flights

The system components were successfully integrated to meet the originally scheduled first flight on July 13, 1998 from Camp Roberts, CA. Seven flights were conducted, six within the Camp Roberts boundaries and one where the aircraft was flown over nearby Ft. Hunter-Liggett up to 60 km from the GPF. Each flight lasted about two hours and began as scheduled at 10:00 AM Pacific Daylight Savings Time. (Aircraft safety considerations prevented night flights with the UAV from McMillan Airfield, but night flights have been conducted with RISTA II.[4]) The last two flights were the formal demonstration where imagery was sent to the East Coast and target nominations, sent cross-continent, were processed.

4.2 Applications

The flights demonstrated the capabilities of the RISTA II system to successfully fill a number of different missions. These included Infrastructure Status and Targeting, Operational Reconnaissance, Time Critical Point Targeting, Route Reconnaissance, Sea Lane Surveillance, Peace Accord Monitoring, Wild Fire Reconnaissance, Narcotics Trans-Shipment Point Observation, Battle Damage Assessment, and Border Surveillance. A few of these are described in this section.

4.2.1 Mobile rocket launcher detection

A key tactical capability demonstrated was the aided target detection of a surrogate Multiple Rocket Launcher (MRL) target. The target report contains the location of the target which was annotated on the map. The sensor was operating in scanning mode for this mission segment. Figure 8 shows the image chip containing the MRL successfully detected by the AiTRAP, along with a view of the Mission Monitor Display showing sensor swath coverage and the target location. Although not shown in Figure 8, successive scans could be stacked to form a wide field of view image. Near real-time stitching of these scans was not demonstrated due to schedule and budgetary constraints. (Software for stitching the imagery for a seamless display is available.) The system software is capable of displaying the entire swath width at 15:1 downsample, an intermediate view subimage at 5:1 downsample, and full resolution imagery (1:1 downsample).

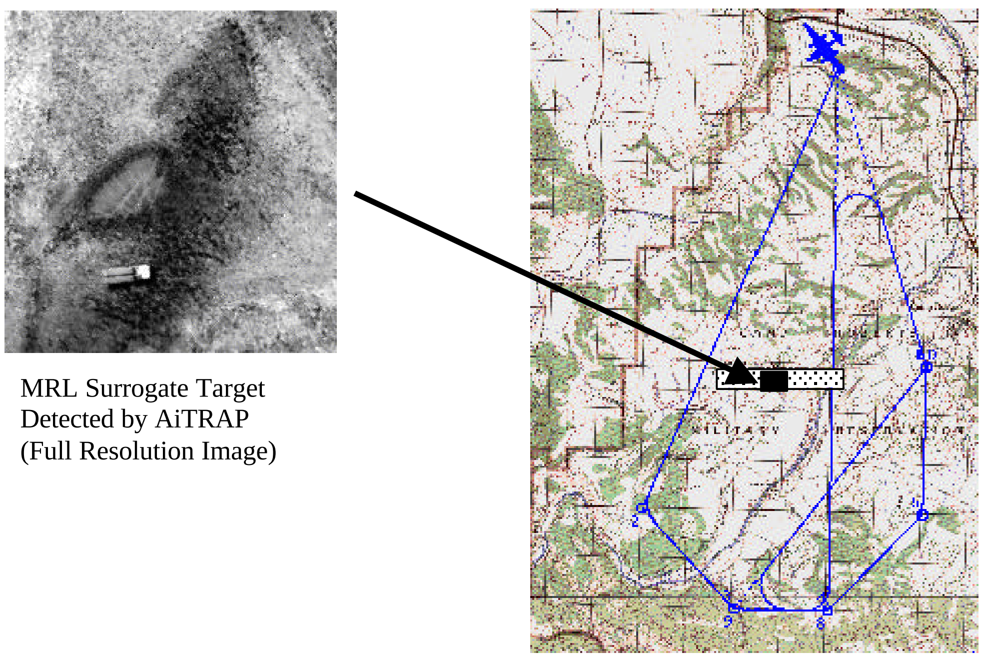
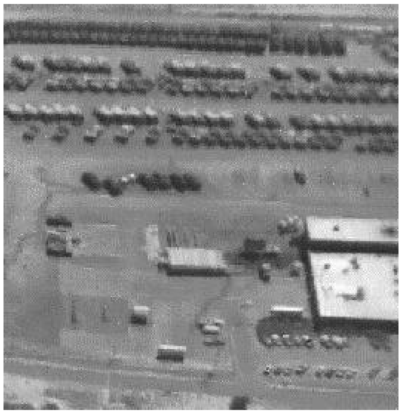


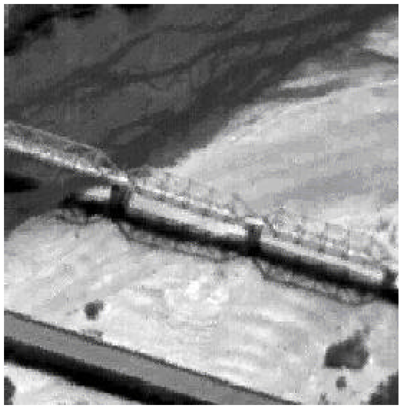
Figure 8. A key capability of the RISTA II system is the ability to automatically detect high value targets over a wide area and automatically report them.

4.2.2 Other applications

The RISTA II sensor also was demonstrated in framing mode, generating video frames at a 15 or 30 Hz rate. This sensor mode is more suited for classical tactical reconnaissance missions. Figure 9 illustrates these capabilities showing imagery of an equipment concentration site and railroad and highway bridges. Note that the shadows near the building in the center of the left picture are due to vehicles which have recently moved from their parking spaces. Figure 9b illustrates a nearby railroad bridge. Such infrastructure surveillance capabilities make the system useful for battle damage assessment (BDA). These capabilities can also be applied to civilian surveillance needs. Figure 10a is a framing mode chip of McMillan Airfield, the small airstrip from which the ALTUS was deployed. The aircraft is a Twin Otter, which is similar in size to aircraft used in drug smuggling. Figure 10b is a similar image of a grass fire. Note how clearly the fire line is visible in the 8-12 micron waveband, whereas in the visible band, the entire area was obscured by smoke, hindering fire-fighting efforts. In the Ft. Hunter Liggett flight the sensor was scanning out in the Pacific Ocean and found a ship 13 km away. In the higher altitude search mode over Ft. Hunter Liggett, the coverage was more than 50 km^2 per minute. A sector scan mode was demonstrated showing that wide area search imagery can be collected while the UAV was in a turn. This can be useful in broken cloud cover, but skies at Camp Roberts were always clear in July.



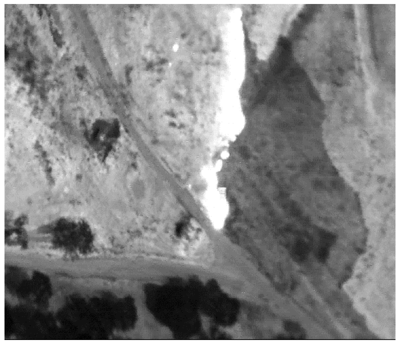
(a)



(b)

Figure 9. The RISTA II system framing modes are suitable for tactical reconnaissance and battle damage assessment.

(a)



(b)

Figure 10. The RISTA II systems reconnaissance capabilities can be applied to civilian surveillance applications such as drug interdiction (a) and wildfire reconnaissance (b).

4.3 Remote tasking

During the formal demonstrations on both 22 and 23 July, observers from Camp Roberts, CA and Rosslyn, VA were given the opportunity to request images of objects of interest accessible from the daily flight pattern. From the East Coast, these requests were keyed in by an operator and sent over the T1 link to the GPF sensor operator. During the course of a UAV loop of Camp Roberts that only took a few minutes, all requests were processed and image chips transmitted to Virginia where they were displayed to the audience. Figure 11 shows three typical image chips. The audience was also able to observe the collection process as it occurred by watching the live mission monitor. (Figure 6)

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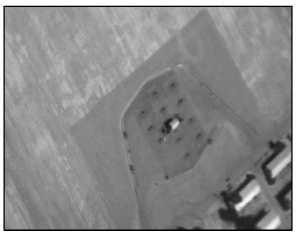
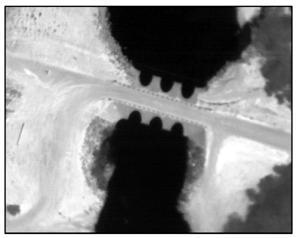


Fuel Point



Low Water Bridge

Figure 11. Three images viewed in Rosslyn based on audience requests.

5. CONCLUSIONS

The RISTA II system maturity and reliability was confirmed; no planned flight hours were lost or delayed. The versatility of the RISTA II system was demonstrated by the wide variety of modes and applications demonstrated on the UAV platform. Further training of the Aided Target Recognition algorithms would allow one to exploit the rapid search capability in numerous additional military and civilian applications.

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